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SANBORNITE, A NEW BARIUM SILICATE MINERAL FROM MARIPOSA COUNTY, CALIFORNIA*†

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I am indebted to Mr. Frank Sanborn of the Division of Mines, Department of Natural Resources, State of California (formerly the State Mining Bureau), for the specimen which contains the new mineral, sanbornite, herein described. This mineral proves to be a triclinic barium dimetasilicate with the formula $BaSi_2O_5$; it is named in honor of Mr. Sanborn in recognition of his faithful work as determinative mineralogist for the past eleven years. According to my reckoning, thirty-nine new minerals in all have been described from California.

The specimen was collected and sent by Mr. Anthony Marsh of Incline, Mariposa County, to the Division of Mines for identification, evidently because of the presence of spots of a rose-red mineral which on careful examination proved to be gillespite, $BaFe''(Si_2O_5)_2$, a mineral recently described from Dry Delta, Alaska Range, Alaska, by Schaller.[1] This is the second known occurrence of gillespite. The locality for the Sanbornite is about one mile north of Trumbull Peak, near Incline. Incline is about five miles west of El Portal, near which there is a commercial deposit of barite recently described by Fitch.[2] The specimen however did not come from a mine or quarry; since lichens are present, it must be an outcrop sample.

The specimen consists largely of quartz with the rose-red spots of gillespite and plates of a cleavable white mineral (sanbornite) with a pearly luster. Thin sections show in addition: diopside, a

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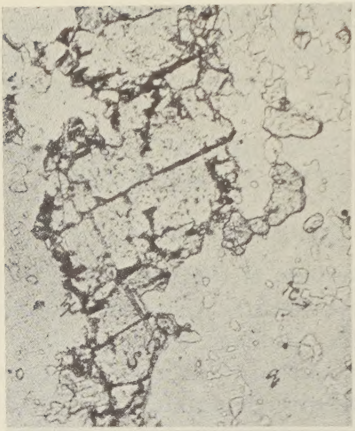
[1] *Jour. Wash. Acad. Sci.*, vol. **12**, pp. 7–8, 1922. *Amer. Mineralogist*, vol. **14**, pp. 319–322, 1929.

[2] *Amer. Mineralogist*, vol. **16**, pp. 461–468, 1931.



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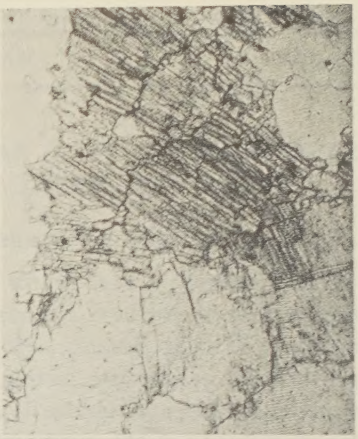

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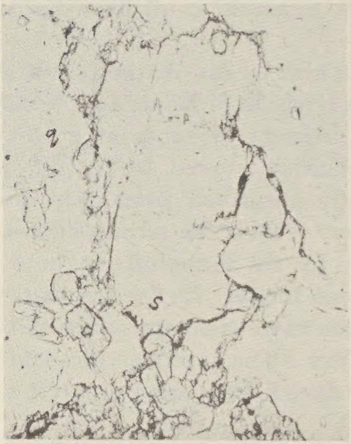

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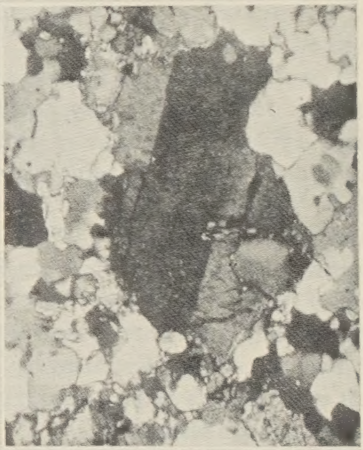

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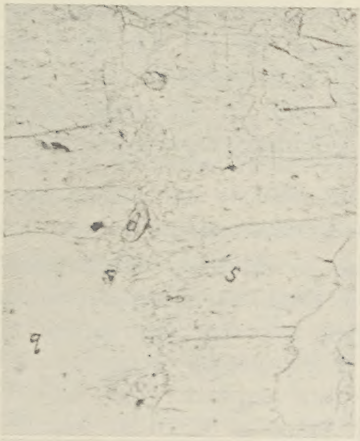
Fig. 1. (× ca. 55 diameters). Anhedral sanbornite (*s*) with alteration product (*x*) in matrix of quartz (*q*), with small celsian (*c*) anhedra.

Fig. 2. (× ca. 55.) Sanbornite parallel to cleavage in lower half and normal to cleavage in upper half.

Fig. 3. (× ca. 55.) Anhedral sanbornite (*s*) in matrix of quartz (*q*). The sanbornite is cut approximately parallel to the (001) cleavage. *d*=diopside.

Fig. 4. (× ca. 55.) The same as Fig. 3 between crossed nicols showing twinning.



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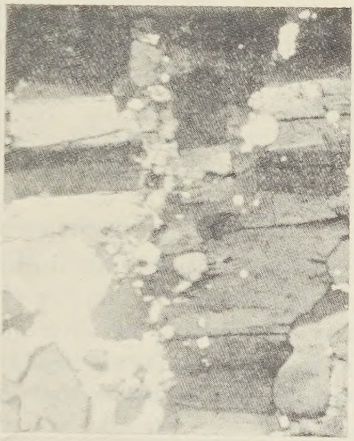

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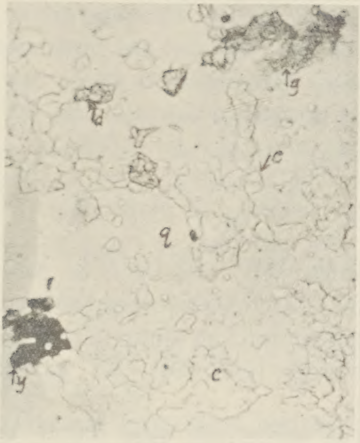

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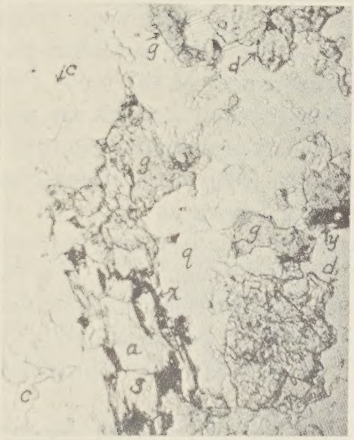

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FIG. 5. (× ca. 55.) Portion of anhedral sanbornite (s) cut approximately parallel to the (001) cleavage. The horizontal lines are traces of the (010) cleavage. d=diopside, q=quartz.

FIG. 7. (× ca. 55.) Celsian (c) anhedra in matrix of quartz. The dark mineral in the upper right-hand corner is gillespite (g), and the one in the lower left-hand corner is the unknown brown pleochroic mineral (y) (probably a new mineral).

FIG. 6. (× ca. 55.) The same as Fig. 5 between crossed nicols showing polysynthetic twinning. [Tw. pl.=(010).] Quartz is shown in the lower left-hand corner.

FIG. 8. (× ca. 55.) This area shows eight minerals: g=gillespite, s=sanbornite, x=alteration product of sanbornite, c=celsian, q=quartz, d=diopside, a=alstonite, (?), y=unknown brown pleochroic mineral.

little tourmaline (schorlite), celsian ($BaAl_2Si_2O_8$), pyrrhotite, and several unknown minerals which also may be new. The sanbornite occurs in veins from a few inches up to 20 inches in width in the metamorphic zone on the western border of the Sierra Nevada batholith. The country rock consists of metamorphosed sediments, largely quartzites and hornfels.

DESCRIPTION OF SANBORNITE

The sanbornite occurs in white to colorless subtransparent plates up to 2 or 3 cm. and 3 or 4 mm. thick. The luster is somewhat pearly. The crystals are unfortunately anhedral; the irregular outlines of Figs. 1 and 3 are typical. A few roughly rectangular subhedral crystals were noted but they are very rare. There is perfect cleavage in one direction which is taken as (001). An imperfect cleavage at about 82° to (001) is selected as (010). In Fig. 2 in the lower part of the photograph the section is cut parallel to the cleavage; in the upper part traces of the perfect cleavage are evident. In Fig. 5 the section is parallel to (001) and the horizontal lines are traces of the (010) cleavage. Here there is also a third cleavage, traces of which are nearly normal to traces of the (010) cleavage. A prominent feature of the mineral is polysynthetic twinning with (010) as twinning-plane. The twinning is not as sharp and well defined as the usual albite twinning of plagioclase. The plates are usually somewhat bent and distorted, so much so that the angle between (001) and twinned ($\underline{001}$) could not be determined with the reflection goniometer. The angle between (001) and twinned ($\underline{001}$) was measured in a thin section and found to be about 16°. In this way the approximate angle $(001:010) = 82°$ was obtained.

Although no euhedral crystals of sanbornite were found, the optical tests prove that it belongs to the triclinic system, as will be shown presently.

The hardness of sanbornite is about 5. The specific gravity determined on 0.3 g. is about 4.19. The value is approximate as the mineral contained a very small amount of included minerals.

CHEMICAL COMPOSITION

Since the sanbornite was decomposed by hydrochloric acid with the separation of silica and gave microchemical tests for barium and aluminum, and showed polysynthetic twinning, it was thought to be the triclinic dimorph of celsian ($BaAl_2Si_2O_8$). It was later discovered that the aluminum came from intimately associated celsian. With the pure mineral no aluminum test could be obtained with cesium chloride and dilute sulfuric acid. My colleague, Professor F. G. Tickell, kindly made several spectrograms of the mineral in the region between 3600 and 5000 Å.U. for me. The very strong barium line at 4934 and good ones at 4131 and 3993 are prominent. Many strontium lines are shown, many calcium lines, one silicon line (3905), and two aluminum lines (3944 and 3961). The spectrographic examination gave a clue of what to expect in the chemical analysis. The aluminum is present in the associated celsian. The calcium is probably present as the carbonate mineral alstonite[3] [$BaCa(CO_3)_2$]. A quantitative analysis made upon one gram of carefully selected mineral which was, however, not quite pure, gave my colleague, Mr. O. C. Shepard, the following results:

Analysis of Sanbornite by O. C. Shepard

	I	II	III	IV	V
SiO_2	42.2	.703	$-.028 = .675$	.675	2.15
Al_2O_3	1.5	.014	$-.014$		
Fe_2O_3	tr				
CaO	0.1	.002	$-.002$		
SrO	0.2	.002	.002	.314	1.00
BaO	50.4	.328	$-.016 = .312$		
Total	94.4				

After taking the aluminum as celsian with equivalent amounts of baryta and silica and the lime as alstonite with an equivalent amount of baryta (column III), we have the ratios of columns IV and V, which lead to the formula: $BaO \cdot 2\ SiO_2$ or $BaSi_2O_5$, barium metadisilicate.

Treated with dilute hydrochloric acid sanbornite behaves in a rather peculiar manner. It is decomposed; the cleavage plates swell and open up into characteristic shreds with weak double refraction which probably have the composition $H_2Si_2O_5$, the hydrogen replacing the barium. A similar phenomenon was noted by Schaller[4] in treating gillespite, $BaFe''(Si_2O_5)_2$, with hydrochloric acid.

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[3] Recent x-ray work by Gossner and Mussgnug (*Centr. Min.*, Abt. A, 1930, pp. 230–238), indicates that alstonite or bromlite is a double salt with the above formula and not an isomorphous mixture of witherite and aragonite.

[4] *Amer. Mineralogist*, vol. **14**, pp. 319–322, 1929.

After standing a few minutes, the hydrochloric acid solution deposits crystals of $BaCl_2 \cdot 2\ H_2O$. These are thin tabular (parallel to 010) crystals, which, as the solution becomes more concentrated, exhibit characteristic polysynthetic twinning. Dilute nitric acid gave isometric barium nitrate and dilute sulfuric acid, granular crystals of barium sulfate, but the barium chloride microchemical test is, I believe, by far the best test for barium. I have never found any mention of it in any of the works on microchemistry.

Optical Properties

The three principal indices of refraction of sanbornite are $n_\alpha = 1.597 \pm .001$, $n_\beta = 1.616 \pm .001$, $n_\gamma = 1.624 \pm .001$, obtained by the immersion method. The values for the α and β directions were obtained on cleavage flakes parallel to $\{001\}$. Other cleavage fragments elongated in the direction of the faster ray and hence parallel to (010) gave the third value n_γ. Since the principal optical sections are not parallel to the cleavage directions, the values for the indices may not be quite correct, but they are very close to the true value on account of the small extinction angles.

In order to determine the indices of refraction to within ± 0.001, a set of liquids differing from each other by 0.01 were used. After an approximate value between $1 \cdot xy0$ and $1 \cdot x(y+1)0$ is found, four drops of one and one drop of the other, three of one and two of the other, two of one and three of the other, and one drop of one and four of the other were used. Each of these five mixed gave four liquids with indices $1 \cdot xy2$, $1 \cdot xy4$, $1 \cdot xy6$, and $1 \cdot xy8$. By using these and the end liquids $1 \cdot xy0$ and $1 \cdot x(y+1)0$, the indices may be determined within 0.001, provided the temperature is taken into account and monochromatic light is used.[5]

The maximum double refraction derived from the indices is: $n_\gamma - n_\alpha = 0.027 \pm .002$. The double refraction obtained by means of a Berek compensator from a thin section, the thickness being found from the maximum retardation of the quartz, is 0.027. The sanbornite has practically the same double refraction as the associated diopside.

Cleavage fragments of the sanbornite are flat plates with a tendency to elongation parallel to the slow ray, sometimes with a fairly straight edge which is the trace of the imperfect (010) edge, and occasionally with a broad twin-band in the same direction. The extinction angle on the (001) cleavage fragments is 3° 36′ (average of 10 varying from 3° to 4°). The extinction angle between two individuals turned on (010) in a section with the highest interference color ($\alpha\gamma$ section) gave 8° 12′ (the average of 10 values). Occasionally cleavage fragments parallel to (010) are encountered and in these the extinction angle is 5° 30′ (average of 10 varying from $4\frac{1}{2}$° to $6\frac{1}{2}$°).

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[5] A Wratten orange (E 22) screen made by the Eastman Kodak Co. may be used as an approximation to sodium light except for very accurate work.

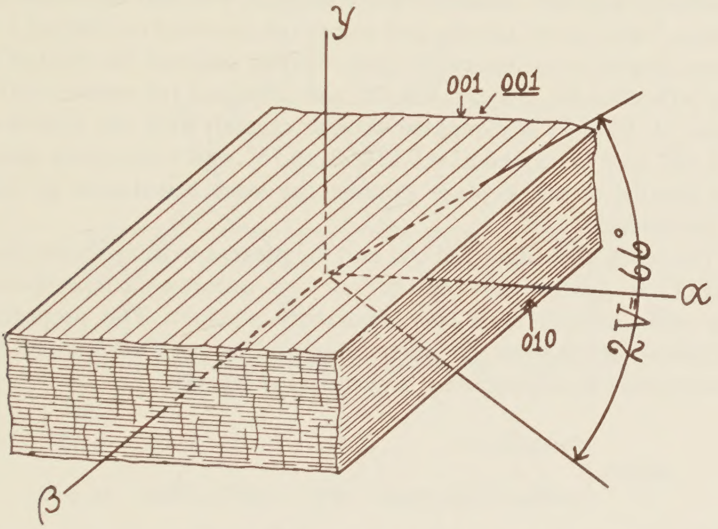

FIG. 9. Optical orientation of sanbornite. The $\alpha\beta$ plane is not quite parallel to (001); the $\beta\gamma$ plane is not quite parallel to (010) and the axial optic plane ($\alpha\gamma$) is not quite normal to (001) and (010).

In thin sections the maximum extinction angles in sections cut normal to the twin-plane is about 10°.

In thin sections parallel to (010) very thin twin-lamellae which make an angle of 3° (average of 10 with the limits $2\frac{1}{2}$ and $3\frac{1}{2}$°) with the (001:010) edge are observed. This suggests polysynthetic twinning analogous to the pericline twinning of plagioclase.

Sections parallel to (001) give an obtuse bisectrix interference figure; sections approximately parallel to (010) give an acute bisectrix figure. The isogyres of the figure are just beyond the field so the axial angle can not be obtained directly. The value of 2V calculated from the indices is 66°. The optical character is negative. The optical orientation is shown in Fig. 9. The plane of the optic axes is approximately normal to (001) and (010) and γ is almost normal to (001). As in other triclinic crystals it is difficult to determine the exact optical orientation.

DIMORPHISM OF BARIUM DIMETASILICATE

While sanbornite is the first simple barium silicate mineral to be discovered, it should be pointed out that barium dimetasilicate ($BaSi_2O_5$) has been obtained artificially. It was first described by Bowen,[6] who found tabular and elongated six-sided crystals of 2 to 3 mm. in size in barium crown glass. Bowen assigned his crystals to the orthorhombic system. Eskola[7] also obtained the orthorhombic form of $BaSi_2O_5$ in elongated tabular crystals with the indices $n_\alpha = 1.597$, $n_\beta = 1.612$, and $n_\gamma = 1.621$, 2V ca. 75°, and with a scaly cleavage parallel to the $\alpha\beta$ plane (almost the same orientation as that of sanbornite).

The work of Bowen, Eskola, and the present writer proves[7a] that $BaSi_2O_5$ is dimorphous; the triclinic form occurs as a mineral and the orthorhombic form is a laboratory product. The properties tabulated below show just such differences as one would expect for dimorphous modifications of a chemical substance.

		n_α	n_β	n_γ	$2V$
$BaSi_2O_5$	Orthorhombic	1.597	1.612	1.621	ca. 75°
	Triclinic (Sanbornite)	1.597	1.616	1.624	ca. 66°

It seems likely that $BaSi_2O_5$ and $K_2Si_2O_5$ are isomorphous.[8] Morey[9] states that a $K_2Si_2O_5$ crystal immersed in a drop of water gives "shred-like forms." There is a hint that $K_2Si_2O_5$ is also dimorphous. Niggli[10] in his observations on $K_2Si_2O_5$ crystals mentions polysynthetic twinning which "resembles albite twinning" and states "the direction of elongation forms a very small angle with the twin-plane." This is very similar to the polysynthetic twinning of sanbornite and suggests that $K_2Si_2O_5$ is dimorphous.

[6] *Jour. Wash. Acad. Sci.*, vol. **8**, pp. 265–268, 1918.

[7] *Amer. Jour. Sci.*, [5] vol. **4**, p. 331, 1922.

[7a] Since this article was written I have found that Nicolardot and Gaubert (*Bull. Soc. fr. Min.*, **51**, pp. 333–8, 1928) have described spherulites of $BaSi_2O_5$ in barium glass They are biaxial and probably triclinic.

[8] Bowen, *loc. cit.*, p. 267.

[9] *Jour. Amer. Chem. Soc.*, vol. **39**, p. 1191, 1917.

[10] *Jour. Am. Chem. Soc.*, vol. **35**, p. 1710.

Morey[11] comments on the rarity of natural disilicates. He cites the rivaite $(Ca,Na_2)Si_2O_5$ of Zambonini as being the only simple nonaluminous disilicate known. Since then, gillespite, $BaFe(Si_2O_5)_2$, has been described and now there is added sanbornite to the list of disilicates.

THE STRUCTURE OF SANBORNITE

In the recent work of structural crystallographers[12] we have valuable contributions toward the elucidation of the structure of silicate minerals. The *x*-ray workers have found evidence of the presence of tetrahedral SiO_4 groups in all silicate minerals thus far investigated.[13] W. L. Bragg[14] and Pauling[15] have simultaneously

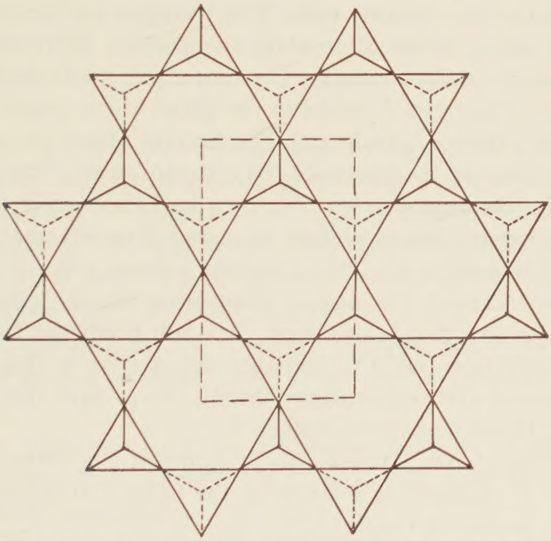

FIG. 10. One layer of the probable structure of Sanbornite. The triangles represent SiO_4 groups. The barium atoms are in the centers of the open hexagons but on levels above and below the plane of the drawing. The unit cell is $2BaSi_2O_5$, shown by the dotted rectangle.

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[11] *Jour. Am. Chem. Soc.*, vol. **36**, p. 225, 1914.

[12] The writer has recently (*Amer. Mineralogist*, vol. **16**, p. 117, 1931) proposed the term *structural crystallography* for the division of crystallography concerned with the internal structure of crystals.

[13] See summary by Gruner, *Amer. Mineralogist*, vol. **16**, pp. 437–454, 1931.

[14] *Zeit. f. Kryst.*, Abt. A, vol. **74**, p. 137, 1930.

[15] *Proc. Nat. Acad. Sci.*, vol. **16**, pp. 123–129, 578–582, 1930.

postulated the presence of interlinked SiO_4 groups for the micas and related minerals which have perfect basal cleavage and pseudohexagonal symmetry.

According to Pauling, the micas, brittle micas, pyrophyllite, the chlorites, and talc all contain the radical Si_4O_{10} or $(Si_3Al)O_{10}$ or $(Si_2Al_2)O_{10}$. Between the sheets of Si_4O_{10} groups the cations lie.

It seems likely that sanbornite has a structure similar to that of the micas and related minerals, though there is no direct evidence that it is pseudohexagonal. Fig. 10 is a drawing of one layer of the probable structure of sanbornite. The triangles are projections of tetrahedra which point alternately in opposite directions. Each tetrahedron has a silicon atom at its center and an oxygen atom at each vertex. The oxygen atoms in the plane of the paper are each common to adjacent tetrahedra. The barium atoms are on higher and lower levels in the center of the open hexagons. The coordination number for barium is six, i.e., each barium atom is connected with three oxygen atoms on one level and three alternate oxygen atoms on the next level. This gives the correct valence for all of the atoms concerned. The unit of structure is $2BaSi_2O_5$ as shown in projection by the dotted rectangle. It is not predicted that this is the exact structure but it is probably one similar to this. The triclinic nature of the sanbornite probably means that the structure is like Fig. 10 but somewhat distorted.

My colleague, Dr. Maurice L. Huggins of the Department of Chemistry is engaged in a study of the crystal structure of sanbornite by means of *x*-rays.

ASSOCIATED MINERALS

GILLESPITE. Of the associated minerals the most interesting is probably gillespite, barium iron dimetasilicate, which occurs in beautiful rose-red anhedral crystals with a perfect cleavage in one direction (001). In thin sections it shows striking pleochroism with the greatest absorption when the cleavage traces are normal to the vibration plane of the lower nicol. Gillespite is shown in Figs. 7 and 8. Isolated fragments with dilute hydrochloric acid give birefringent shreds ($8SiO_2 \cdot 5H_2O$ according to Schaller)[16] and microchemical tests for iron and barium.[17]

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[16] *Amer. Mineralogist*, vol. **14**, p. 320, 1929.

[17] The barium chloride test mentioned on p. 165.

CELSIAN. A rather inconspicuous mineral scattered through the quartz matrix and often intimately associated with the sanbornite was with some difficulty identified as celsian ($BaAl_2Si_2O_8$), the rare barium feldspar. This is, I believe, the first mention of celsian in the United States. It was identified by microchemical tests for barium ($BaCl_2 \cdot 2H_2O$ from an HCl solution) and aluminum (cesium alum with CsCl and dilute H_2SO_4), refractive index of 1.590 ±.005, double refraction about the same as that of quartz, and an extinction angle of 28° (average of 5 readings) measured against the cleavage cracks parallel to (001), this vibration direction being the slow ray. The maximum size of the celsian grains is only 0.13 mm., but the identification is certain. Celsian is shown in Figs. 1, 7, and 8.

ALSTONITE. A carbonate mineral with strong double refraction, change of relief, and no indication of cleavage is identified as alstonite (or bromlite),[17a] which according to the recent work of Gossner and Mussgnug[18] is a double salt with the formula $BaCa(CO_3)_2$. The identification rests largely upon the axial angle 2V which is 8° 30′ (7° 14′ recorded value for alstonite).

DIOPSIDE, TOURMALINE (SCHORLITE), QUARTZ, and PYRRHOTITE are identified in thin sections. There are no special features worthy of comment.

UNKNOWN MINERALS. There are three minerals which have not yet been identified. These are in all probablity new minerals.[18a] They are briefly described:

First there is *x*, an alteration product of sanbornite. It is pale brown and appears opaque white by reflected light. The index of refraction is less than Canada balsam. It is probably a hydrous barium silicate, though this is not certain. It is well shown in Figs. 1 and 8.

The next is *y*, a brown mineral with very high relief and strong absorption. It is present in small amounts. Fig. 8 (lower left-hand corner) is typical of this mineral.

The next is *z*, a pale yellow isotropic mineral with low relief.

[17a] This is probably witherite since no micro-chemical test for calcium could be obtained.

[18] *Loc. cit.*

[18a] Since this article was written better material has been obtained. It is my intention to describe these minerals at a later date.

SUMMARY

Sanbornite is a triclinic form of barium metadisilicate with the formula $BaSi_2O_5$. It occurs near Incline, Mariposa County, California, associated with gillespite, celsian, diopside, tourmaline, quartz, pyrrhotite, and three unknown minerals which may be new. It is probably from a contact metamorphic zone.

Tabular anhedral crystals show a perfect (001) cleavage and an imperfect (010) cleavage. The extinction angles on these two faces are respectively 3° 36′ and 5° 30′. Polysynthetic twinning with (010) as the twin-plane is a prominent feature. The maximum extinction angle in sections normal to the twin-plane is about 10°. The principal indices of refraction are $n_\alpha = 1.597$, $n_\beta = 1.616$, $n_\gamma = 1.624$, all $\pm .001$. The maximum double refraction is 0.027. The plane of the optic axes is approximately normal to (010) and γ is approximately normal to (001). 2V calculated from the indices is 66°.

Sanbornite is decomposed by cold dilute hydrochloric acid with the production of birefringent shreds of $H_2Si_2O_5$ (?). The solution on evaporation furnishes a microchemical test for barium ($BaCl_2 \cdot 2H_2O$ in characterisitic polysynthetically-twinned thin tabular crystals).

ACKNOWLEDGMENTS

I am indebted to Mr. Frank Sanborn for the specimen of gillespite on which the description is based, to Mr. Anthony Marsh and Mr. James Law for the opportunity of visiting the locality, to Mr. John Melhase of Berkeley, California, for a generous supply of specimens, to Mr. E. H. Murchison of El Portal for information concerning the locality, to Dr. Aaron C. Waters for help and suggestions, to Mr. O. C. Shepard for the chemical analysis, to Professor F. G. Tickell for the spectrograms, to Dr. M. L. Huggins for suggestions concerning the probable structure, to Mr. Alexander Tihonravov for thin sections, and to Mr. W. W. Bradley, State Mineralogist of California, for permission to publish this article.

CESIUM BIOTITE FROM CUSTER COUNTY, SOUTH DAKOTA

Frank L. Hess[1] and J. J. Fahey[2]

Foreword. (F. L. H.) In 1927 when there was considerable interest in the discovery of cesium minerals, Judge Harry E. Way of the Custer County Court at Custer, South Dakota, who had formerly been actively engaged in mining, undertook the spectroscopic examination of the minerals of the Black Hills for the rare alkali metals. He did not confine his efforts to any particular class of minerals but tested many. Among specimens submitted by George B. Grant he found cesium in lepidolite, beryl, and in another mineral which proved to be the rare pollucite. All three specimens were collected from Tin Mountain, about 7 miles west of Custer, and appear to belong to the higher temperature pegmatite minerals. Judge Way also found cesium, rubidium, and lithium in a dark mica, which forms the basis of this article.

It is worthy of remark that I had collected from the vicinity specimens of beryl which two interested chemists tested spectroscopically for cesium with negative results. It seems possible either that part of the beryl from the pegmatite is barren of cesium or that the temperature of the flames used was not high enough. Judge Way ground his sample and mixed it with fluorspar. A little of the powder was then wet and some of the mixture was applied to a charred match, which was held in a prestolite (acetylene) flame in front of the spectroscope. His results were excellent.

Occurrence. In 1928, with Mr. George B. Grant of Custer, I visited Tin Mountain and made a reconnaissance of the neighborhood. The "Mountain" has an altitude of somewhat more than 6,400 feet and rises about 100 feet above Warren Creek, a rivulet which has cut it off from a ridge at the north.

The country rock, a dark gray quartz-mica schist, forms the body of the hill, but the crest is a pegmatite which shows in the outcrop large masses of pink and buff colored microcline, and quartz with imbedded crystals of spodumene 8 or 10 feet long. In the quartz are crystals of amblygonite, several inches in diameter, and in an indistinct quartz vein and the adjacent pegmatite, is cassiterite, whence the name of the hill. At one time an effort was made to work the pegmatite for tin. The property is owned by the Maywood Chemical Works and in the course of mining the firm has exposed very much larger crystals of amblygonite and spodumene, and heretofore unheard of masses of pollucite. The mass of pegmatite in Tin Mountain is an enlargement at the west end of a vertical pegmatite which strikes N. 80° E. On the east side of Warren Creek the pegmatite is about 60 feet wide and extends eastward possibly a half-mile as an incongruous mixture of feldspar and quartz, becoming disconnected masses. Near the east end on the Lithia claim of the Maywood Chemical Works, a short drift has been driven into the pegmatite, which is here only 5 to 8 feet thick, seems to be almost flat and dips slightly N. 40° E. It consists mostly of quartz with a little muscovite in diamond shaped plates, at most 4 or 5 inches across, and some amblygonite crystals which reach the size of a man's head. Two small chunks greatly cracked but, fresh, were said to be pollucite carrying 27 per cent Cs_2O. Near the margins are masses of microcline mixed with muscovite in books ½ inch across and thick, tiny crystals of cassiterite and a little black tourmaline. The pegmatite also carries some white beryl and columbite, all in small crystals.

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[1] Published by permission of the Director of the U. S. Bureau of Mines.

[2] Participation by permission of the Acting Director of the U. S. Geological Survey.

The quartz-mica schist grows coarser near the pegmatite. Inclusions of the schist one to two inches thick have been replaced by a black mica with the foliae lying parallel to the wall, and similar mica forms part of the schist wall. It was this mica from which Judge Way obtained strong spectrographic tests for caesium, rubidium, and lithium.

It was unpromising looking material, particularly as it came from the outside, the coolest part of the pegmatite, whereas the known cesium-bearing minerals, are found in that part of the pegmatite which has been the hottest.

Under the microscope a section appeared to be fairly pure, the principal inclusions were tiny grains of apatite, but the mica flakes contained numerous cloudy pleochroic halos, without rings, each surrouding a tiny zircon (?).

Analysis: (J. J. F.) The mica was crushed and carefully selected under a binocular microscope. It seemed to be remarkably pure and after the rejection of a small quantity of extraneous material no gangue could be seen under the microscope. The mica is strongly pleochroic, from nearly colorless to deep brown. It is biaxial, optically negative, and the indexes, measured by immersion in oil were: $\alpha=1.573$; $\beta=1.620$; $\gamma=1.620$. The specific gravity at 25° C. = 3.10.

In analysis the methods of Hillebrand were followed with the exception of those for K_2O and Cs_2O. Unfortunately there is no satisfactory direct method for the quantitative determination of K_2O and Cs_2O occurring in the same specimen. The following indirect method was found to give very good results.

The alkalies of a 0.5000 gram sample were obtained as chlorides by the method of J. Lawrence Smith. To the water solution of these alkali chlorides an excess of chloroplatinic acid was added. This solution was evaporated to dryness on the steam bath and then drenched and scrubbed with alcohol until any excess of chloroplatinic acid and any alcohol-soluble chloroplatinates were removed. The insoluble residue, which consisted of K_2PtCl_6 and Cs_2PtCl_6, was collected on a weighed ground glass filter, dried at 110° C. for one hour to remove adhering alcohol and weighed. The weight of the K_2PtCl_6 plus Cs_2PtCl_6 was 0.2450 gram. This was then dissolved in hot water and the platinum contained therein precipitated by magnesium, the excess magnesium dissolved in hydrochloric acid, the platinum filtered, ignited, and weighed. The platinum weighed 0.0942 gram.

From the above data; *i.e.*, the weight of the K_2PtCl_6 plus Cs_2PtCl_6 and the weight of the platinum derived therefrom, the percentages of K_2O and Cs_2O in the sample were determined as follows:

If all of the 0.2450 gram were K_2PtCl_6, the Pt would weight 0.0984 gram. The 0.2450 gram actually yielded Pt that weighed 0.0942 gram. If all of the 0.2450 gram were Cs_2PtCl_6 the Pt would weigh 0.0710 gram.

$$0.2450 \times \frac{(0.0942-0.0710)}{(0.0984-0.0710)}=0.2074 \text{ gram } K_2PtCl_6$$

$$0.2450-0.2074=0.0376 \text{ gram } Cs_2PtCl_6$$

$$0.2074 \text{ gram } K_2PtCl_6=0.0402 \text{ gram } K_2O=8.04 \text{ per cent } K_2O$$

$$0.0376 \text{ gram } Cs_2PtCl_6=0.0157 \text{ gram } Cs_2O=3.14 \text{ per cent } Cs_2O$$

The complete analysis of the sample follows:

	Per cent
SiO_2	36.97
TiO_2	2.64
Fe_2O_3	2.26
Al_2O_3	17.51
FeO	14.81

MnO	0.22
MgO	8.45
Li_2O	0.65
Na_2O	0.45
K_2O	8.04
Cs_2O	3.14
$H_2O-110°C$	0.32
$H_2O+110°C$	2.48
F	3.17
	101.11
Minus Oxygen equiv. of F	1.34
Total	99.77

Mineral Affiliations. (F. L. H.) The physical characteristics and the analysis throw the mineral into that micaceous scrap heap known as biotite, although it is only a little too low in iron oxides to fit in the lepidomelane group.

It is the first mica, other than lepidolite, known to carry cesium. Micas of similar appearance were found at the border of the pegmatite on Tin Mountain, the west terminus of the pegmatite described earlier in this paper, at the border of cesium bearing pegmatites in the town of Newry, and on Hodgeon Hill, near Buckfield, Maine. Judge Way found no cesium in the biotite from Tin Mountain but got very strong rubidium lines. We obtained strong lithium and rubidium and faint cesium lines. Mr. Fahey's spectroscopic tests of the mica from Hodgeon Hill showed neither cesium nor rubidium. The biotite from Newry has not been tested, but a biotite from the wall of the Morefield pegmatite at Winterham, Va. (3 miles west of Richmond) gave good lithium lines.

It is of interest to a geologist to find a cesium mineral in the cooler parts of a pegmatite. As already stated, pollucite, lepidolite, and beryl, the principal known cesium-bearing minerals, are found in those parts of the pegmatite through which the hottest solutions have apparently flowed. The explanation seems to lie in the type of solution which brought the element from the depths, and the fluorine, which is above the average reported for biotite, may have carried it into the cooler parts of the pegmatite, just as tin seems to travel with antimony and sulphur, into much cooler parts of veins than can be reached by tin which deposits only as oxide.

THE SIGNIFICANCE OF "BLOCK STRUCTURE" IN CRYSTALS

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ABSTRACT

An apparent subdivision into block-like subunits in almost parallel orientation is very common in crystals. It is shown that actually the subunits are not separate blocks or grains, but are continuous with each other by way of the parent crystal nucleus, forming a rudely spherically-symmetrical, tree-like structure. The term *lineages* is introduced to cover such crystal subdivisions. The origin of lineages is ascribed to structural distortions, which, in turn, are surmised to arise either from the Zwicky surface cracks in crystals or from improperly distributed solid solution impurities. A much larger spacing is ascribed to the Zwicky cracks while the crystal is immersed in its depositing solution.

Lineage boundaries are loci of negative crystals and voids, and probably localize exsolution and replacement.

Anyone who has attempted to find flawless material for gliding experiments can not have helped making the observation that in the ideal sense genuinely continuous single crystals of some species are not obtainable in anything but the smallest bits. A similar observation must have been made by all those who have attempted to make goniometric measurements on the surface planes of crystals. The writer has had occasion to observe that galena, natural and artificially grown alkali halides, pyrite, and marcasite, especially, cause not a few experimental difficulties because of imperfections in this respect.*

The condition is apparent in two very striking ways. First, the surface of a crystal (certain Joplin galena and marcasite, and certain pyrite display it well) often has the appearance of being composed of many smaller crystals stacked together in almost parallel position, but with enough difference in orientation so that its cumulative effect sometimes gives rise to a twisted appearance of the major unit. The individual subunits may in themselves display all the forms common for the mineral in that locality,[1] (see Figures 1–4). Mild cases of this condition (as distinct from vicinal faces) are an annoyance to the goniometer investigator.

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* This statement does not imply that this feature is peculiar to the crystals mentioned. Once one's attention has been called to the condition described beyond, it can be recognized on almost any crystal whatever.

[1] There need be no confusion of this feature with certain types of natural etching.

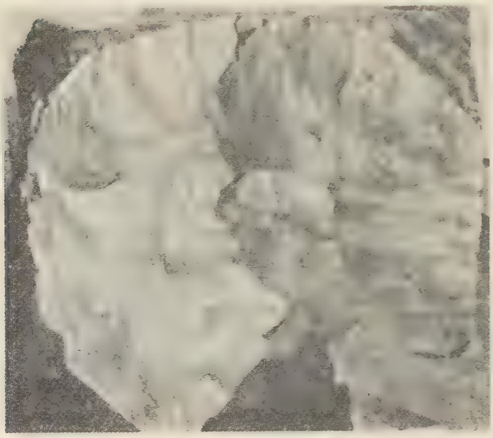

Fig. 1. Galena from Joplin, $\frac{2}{3}$ natural size. The specimen was illuminated so that the lineage development is brought out. The peripheral regions of the top and right, especially, illustrate the radial tendency of lineages. Some of the larger blocks, as the one in the center, are in themselves composed of a number of lineages, each a descendant within a family, so to speak, from the parent lineage represented by the block.

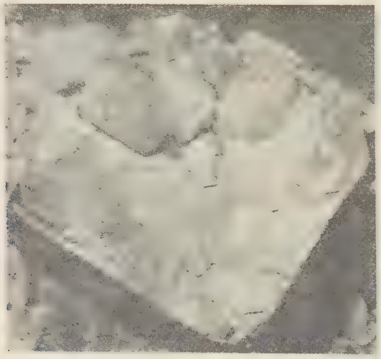

Fig. 2. Galena crystal on dolomite, with chalcopyrite; Joplin, natural size The cube has been illuminated to bring out some of the surface evidences of lineage structure. Sharp shadows mark the crystal off into blocks of cubo-octahedral outline. These are the major lineage families. Each of these is further subdivided into the less conspicuous individual lineages made visible by mottling. This feature is more easily observed by actually rotating the specimen and observing the changes in illumination.

Second, minerals with good cleavage like galena allow one to examine this feature in the interior. Head[2] has recently noted this characteristic in the Joplin galena. Superficially, it appears that the crystal is simply an inter-growth of separate individuals in almost parallel position. The whole cleavage surface is an irregular mosaic of different grains. For the most part, the grains are de-

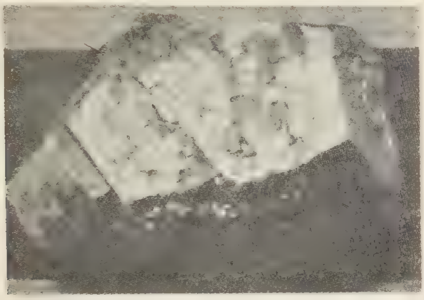

FIG. 3. Pyrite from Elba, natural size. Mosaic of lineages on pentagonal face of pyritohedron.

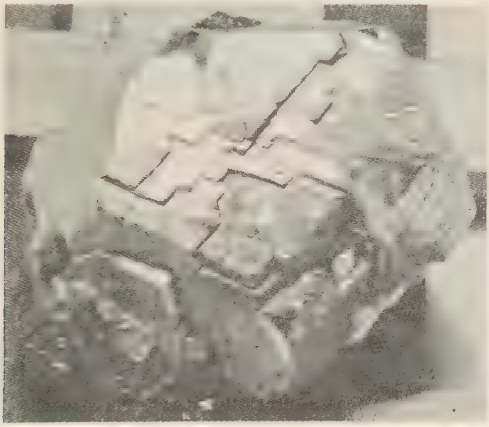

FIG. 4. Pyrite from Elba, natural size. The pyritohedral face is clearly cut up into sharp blocks which represent families of lineages. The individual lineages within the family blocks are indicated by a faint mottling. This is most apparent in the upper block.

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[2] R. E. Head, The Cleavage Surfaces of Galena: *American Mineralogist,* **16,** 1931, 345–351.

cidedly elongated, and as Head has remarked, they have a distinctly radial arrangement. The grain boundaries are visible almost wholly because adjacent grains differ slightly in orientation and therefore the cleavage of each grain (the aggregate of all of which make the ordinary galena cleavage) differs very slightly in slope from that of its neighbors. With diffuse light, this condition is not striking, but with a sharp source of light it can not be missed.

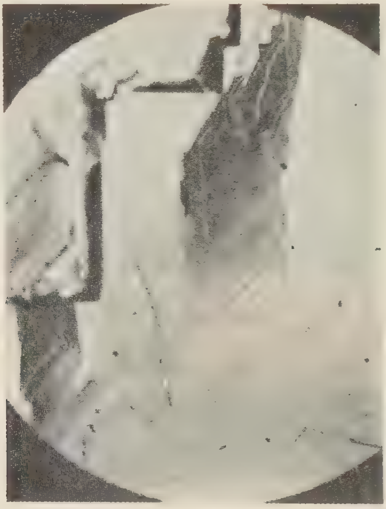

FIG. 5. Photomicrograph of galena cleavage surface, ×43. This photograph was taken with normal illumination using a metallographic microscope, with the cleavage surface tipped slightly so as to give a maximum contrast between several lineages. The parent crystal stock is at the bottom of the photograph. Between a quarter and half way up, this splits into four branches, a dark one at the left, another dark one in the center, and alternating light ones. Degree of illumination is a measure of degree of deviation from the parent orientation. This illustration is especially introduced to indicate the derivation of the central dark lineage from the parent stock and its gradual change in orientation. The square motif is the cubic cleavage traces. The fine lines on the surface will be discussed in a later paper.

If the observation goes no farther than this the intrinsic nature of the situation is overlooked. The key to the explanation of the phenomenon is found in the fact that the orientation discrepancies between neighboring blocks are least near the center of the crystal and increase toward the edges, and, most important, grains which are discrete near the periphery of the crystal, when followed back to the center are found to join in one and the same parent grain.[3] Figure 5 gives photographic proof of this. In other words, the different "grains" are not actually different grains in the ordinary sense, but are really one and the same grain, connecting by way of the original nucleus. Figure 6 illustrates this relationship diagrammatically for the two-dimensional analog of a crystal.

The writer proposes the name *lineages* for all such "grains" whose orientations descend continuously from the same parent nucleus but whose mutual orientations may differ. Some such term is plainly called for since in the strictest sense all descendants from the same nucleus are the same grain and in the best sense they are also the same crystal. In this nomenclature, the discontinuities which mark the cleavage surfaces of a single crystal, such as those under discussion for galena, are *lineage boundaries.*

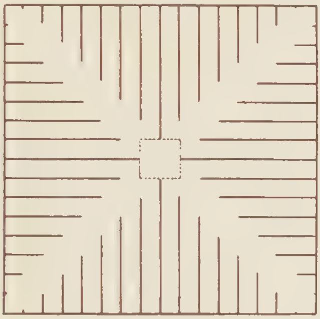

FIG. 6. Two dimensional analogue of a cube subdivided into lineages. All lineages are descended from the central (dotted) nuclear cube, and all are parts of a continuous structure. This illustration is highly diagrammatic and much too simple, partly because the third dimension complicates the structure and partly because natural lineages are much less regular. The scheme, however, is intrinsically correct. The parallel peripheral lineages may be seen in the galena of Figure 1.

The reason for the "parallel" part of the sub-parallel grouping is clear: the orientation is inherited by direct line of descent from the original crystal nucleus, with slight modification. One of the characteristics of the modification is that it is continuous and does not suffer sudden breaks. It appears evident without the necessity of any special argument that the only thing capable of causing a continuous change in orientation from parent nucleus to final crystal exterior is a structural distortion (so-called "lattice distortion").

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[3] Because of the three dimensional nature of the crystal, all neighboring grains can not be followed to a common single source for most of the joining takes place at some other depth than that of the cleavage surface under observation.

The question arises, what causes structural distortion? It appears that it may arise from two distinct sources, which may be briefly designated *surface effect* and *solid solution.* It further appears that neither of these two effects is sufficient to cause lasting distortion unless crystallization takes place under essentially nonequilibrium conditions.

SURFACE EFFECT

The evidence for the existence of cracks in crystal surfaces has been reviewed by Zwicky in one of his earlier papers on the mosaic structure in crystals.[4] The presence of these flaws has been suggested along two main lines of independent evidence: the discrepancies in expected and experimental strengths of solid materials, and the calculated surface contraction in ionic crystals.

It has been realized for some time that the experimental strength of solid materials, including polycrystalline aggregates, single crystals, and even glass, is not of the order of magnitude demanded by theoretical considerations of various sorts, but is much too small.

Having in mind particularly polycrystalline aggregates and glass, Griffith[5] has suggested and given very convincing argument in support of the thesis, that the subnormal experimental strength owes its origin to surface cracks. Zwicky[6] adopted this hypothesis for the preliminary form of his mosaic crystal theory, with rather special application to single crystals.

A second line of evidence is derived from direct calculations. Lennard-Jones and Dent[7] have shown that the surface layers of the sodium chloride structural type crystals (and this includes galena, admitting that the latter is ionic) must contract linearly some five odd per cent. They conclude, in part (p. 258):

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[4] F. Zwicky, On the Imperfections of Crystals: *Proc. Nat. Acad. Sci.*, **15,** 1929, 253–259.

[5] A. A. Griffith, The Theory of Rupture: *Proc. of the First Int. Cong. for Applied Mechanics,* Delft, **1925,** 55–63.

[6] *Op. cit.*

[7] J. E. Lennard-Jones and Beryl M. Dent, The Change in Lattice Spacing at a Crystal Boundary: *Proc. Royal Soc.*, (A) 121, **1928,** 247–259.

> The general tendency will . . . be toward contraction and this may lead to cracking at the surface.

This opinion was pronounced quite independently of any knowledge of Griffith's conclusions, the research being undertaken for the purpose of investigating whether or not the surface contraction which was apparently required by the results of experiments on electron scattering by crystals, was to be expected.

In order to gain a visual conception of how surface cracks may account for distorted structure, Figure 7 is introduced. This represents a (100) cross-section of an NaCl-type crystal. Because of the surface contraction necessary for a crystal of this type, the surface is in equilibrium only if the contraction strains are relieved by checking as indicated by the wedging cracks. For ionic crystals the order of magnitude of the spacing between cracks, is controlled, to a first approximation, by the fact that the greatest differential contraction between a pair of (001) planes A and B must not bring an ion in the upper plane opposite one of like sign in the lower plane. For most of the simple ionic crystals, like, say, the alkali halides, this gives the following relation:

$$\frac{\Delta c}{2} \sim \frac{a}{2} \qquad (1)$$

where Δc is the maximum differential contraction between a pair of planes, and a is the length of a unit cell.

Taking Δc as of the order of magnitude of the total contraction, c,

$$\frac{c}{2} \sim \frac{a}{2} \qquad (2)$$

Introducing the 5 per cent contraction calculated by Lennard-Jones and Dent, this leads to

$$\frac{5}{100} d \sim a \qquad (3)$$

where d is the spacing between cracks.

or

$$d \sim 20a \qquad (4)$$

For the alkali halides and galena, this amounts to a spacing between cracks of about 100Å. This far we essentially follow Zwicky with regard to the checking of crystal surfaces.

The writer will presently propose an abnormal development of surface checking as an origin of lineage boundaries. In the present form of the theory of checking, however, the correlation is not very obvious because the distance expected between cracks, some 100Å, is not of the order of magnitude of the lineage boundary spacings, which can be measured in millimeters in the alkali halides and galena. Zwicky's approximations, however, require additional considerations, all of which tend to increase the spacing of the cracks:

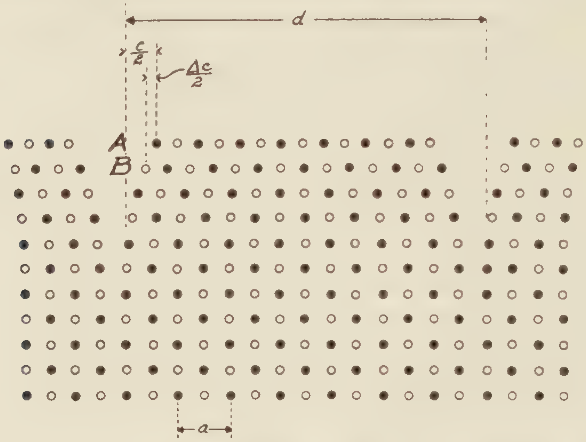

FIG. 7. Cross section of an NaCl-type structure on (100), showing cracks resulting from contraction of surface planes. Highly diagrammatic, simplified, and not to scale.

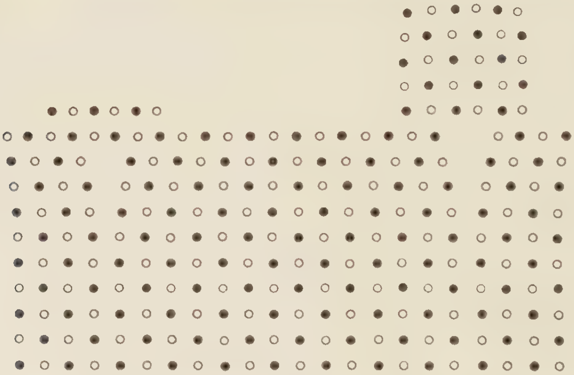

FIG. 8. The keying of the cracks shown in Figure 7, to form permanent distortions and lineages. Crack at left keyed by deposition of two layers of ions; crack at right keyed by precipitation of crystalline block. Diagrammatic.

(1) Lineages are developed during the actual growth of the crystal. In a majority of the cases which come up for consideration,

especially in the mineral kingdom, the crystal is deposited from some sort of liquid solution. The degree of surface contraction calculated by Lennard-Jones and Dent must be considerably modified if one takes account of this more complicated condition. In the absence of any very exact knowledge of the mechanism of crystallization, it is not easy to see just the extent of the modification, but it is to be expected that the direction of the change will be such as to decrease the quantity of contraction by a very considerable amount. The calculations have been made for a completely isolated single plane. The authors[8] say in this connection:

> A full investigation of this effect, taking into account the influence of the rest of the crystal, is not attempted here, but some indication of its magnitude may be obtained by considering the spacing in a single isolated layer. This will give an *upper limit* to the effect. [Italics by M.J.B.]

and also:

> The decrease is seen to be of the order of 5 or 6 per cent. The actual decrease in the surface layer will, of course, be less than this owing to the restraining influence of the lower layers.

Now, if not only the body of the crystal under the isolated plane is taken into account, but also the "restraining influence" of the mass of quasi-crystalline material, both solute and solvent, in the saturated layer just at the surface of the crystal, the situation is quite different. The external plane in question finds itself in an environment which is more like the normal interior of a crystal than like that of an isolated plane, and the contraction must not only be less, but, as a guess, must be orders of magnitude less, than that calculated for an isolated plane.

This effects the spacing of cracks in two ways. First, the coefficient 5/100 in (3) becomes very much smaller, hence the spacing, d, proportionally larger. Second, the surface plane is no longer in a region of such a sharp gradient in the field, because of the fact that the crystal bits, coordinated groups, or molecules of the solute, and molecules of the solvent as well, all oriented near this surface, effect a more gradual change in the field than is the case when the crystal is in contact with, let us say, air. For this reason, the differential contraction at the two surface layers is not vastly greater than that of the next pair of planes. In other words, the differential contraction gradient follows the field gradient and this is relatively gradual in the region of the crystal boundary. Therefore, the differential contraction of the two surface layers can no longer be taken as of the order of magnitude of the total contraction, but will be of a lower order, for the contraction is more uniformly distributed among the planes. This still further lowers the order of magnitude of the coefficient given as 5/100 in (3), and consequently raises the order of magnitude of the spacing, *d*.

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[8] Lennard-Jones and Dent. *Op. cit.*, 256 and 258.

Apparent confirmation of the suggestion that contact with the solvent increases the crack spacing, is to be found in the experiments of Joffé[9] and his collaborators. Like other substances, rock salt shows an experimental strength inferior to its theoretical strength. The experimental strength is greater than usual, however when tested on pieces of the order of magnitude of 10^{-5} or 10^{-6} cms., from which it has been concluded that this is about the spacing of the surface cracks. When, however, the experimental strength is measured on specimens which are normal except that they have a wetted surface, Joffé finds that the strength approaches the theoretical limit. This anomalous increase appears to be in harmony with a large increase in the spacing of the cracks when in contact with a solvent.

(2) For crystals capable of easy translation-gliding, it is not absolutely necessary that the condition be obeyed which limits the maximum differential contraction to the length of a unit cell. A contraction of more than this amount would be no more serious to the stability and the solidity of the crystal than the condition of a crystal after bend-gliding.[10] For any crystal which can translation-glide, it is easy to imagine a condition of checked surface such that the lengths of the checks are indefinitely large (or possibly limited by some minimum energy condition) in a translation-gliding direction and of the width indicated by relation (4). In this case the cracks transverse to the gliding direction would attain major proportions, while those parallel to it would be of normal width. In the case of crystals composed of highly polarizable ions, and having, therefore, unusual translation-gliding possibilities, such as galena with translation $T=\{001\}$, $t=[100]$,[11] the checks might be of extranormal extent in all directions.

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[9] Abram F. Joffé, The Physics of Crystals: *New York*, **1928,** especially pages 62–66.

[10] M. J. Buerger, Translation-gliding in Crystals: *American Mineralogist*, **15,** 1930, 50–51.

[11] M. J. Buerger, Translation-gliding in Crystals of the NaCl structural type: *American Mineralogist*, **15,** 1930, 235–236.

These considerations would appear to indicate that the cracking of a crystal surface, following the main theme developed by Zwicky, might in part, at least, be a cause of lineage formation, simply because the checking of the surface separates the crystal into lineage-like blocks which speculation indicates may be of the same general order of size as the observed lineages. Furthermore, the structure in the region of a crack is considerably distorted. Under normal conditions the distortion can not be cumulatively inherited by crystal substance yet to be deposited, for the simple reason that as the crystal grows, the crack closes behind as new layers are added ahead. Under normal conditions, therefore, the crack is lasting but insignificant, while the distortion at any given spot is ephemeral.

Under near-equilibrium conditions of crystallization, therefore, one would not expect lineages to form, and this is apparently just the case. The ideal crystals which are a pleasure to handle on the goniometer would be of this near-equilibrium grown type. Every crystallographer knows how rare such material is, a situation in line with one's expectancy of near-equilibrium conditions of crystallization.

Under conditions of rapid crystallization, there appear ways of maintaining the separation of the crystal into the branches (*i.e.*, lineages) produced by the cracks, and ways of maintaining the structural distortion caused by the crack. To gain a visual picture of this, suppose that addition of new material to the surface of the crystal takes place by the attachment of ions or coordination groups. A crack is bound to be bridged by this rather plastic juvenile material as indicated in Figure 8, and before it has a chance to compete, as in normal equilibrium, for a more secure perch, it is covered by another layer which seals the whole arrangement. The same would be expected to come about if new material is added to the surface as minute crystal blocks (Figure 8). This latter possibility is rather suggested for crystallizations from a viscous substance, from supercooled liquids,[12] and possibly for ordinary crystallizations.[13] Each crack-bounded surface patch, with cracks so keyed, becomes a possible lineage, both because of splitting of the original structure and because of the splitting which becomes necessary from the distortion introduced by the keying. It follows that the width between lineage boundaries formed according to this theory can not be less than the width between cracks. This extreme condition prevails when every crack is keyed, a condition to be expected under very rapid growth. Once completely keyed in this fashion, no more cracks could form until the volume growth of the crystal provided a materially larger surface, for the development of lineages automatically splits the crystal up into grain-like patches whose surface contraction does not exceed the ability of the surface to contract as an entity. This state of affairs seems in harmony with what is observed on galena cleavages, where the sizes of the lineages are more or less uniform for a given crystal, and their shapes are prism-like, the prism extending from the center and branching peripherally.

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[12] J. T. Randall, H. P. Rooksby and B. S. Cooper, *X*-ray Diffraction and the Structure of Vitreous Solids-I: *Zeit. Kristallographie*, **75**, 1930, 196–214.

[13] E. W. Skinner, Diffraction of *X*-rays in Liquids: Effect of Temperature: *Physical Review*, **36**, 1930, 1625–1630.

Finally, with conditions between the extremely rapid growth and near-equilibrium growth, one would expect fewer cracks keyed, and larger lineages. In other words, the more slowly a crystal is grown, the more nearly it should conform to the ideal single crystal from the point of view of continuity of structure.

Solid Solution

A second possible cause for structural distortions serious enough to give rise to lineages, is solid solution. Since no two species of atoms are alike in properties, especially in the property, effective size, or in the more fundamental properties, polarizability, deformability, etc., it follows that if one species[14] proxies for another in solid solution, it must be distributed either with complete regularity or with complete randomness in order that a cumulative structural distortion may not arise. If neither condition is fulfilled, a distortion must appear commensurate with the lack of uniformity. Upon growth of the crystal, a point will eventually be reached where, instead of continuing as a severely distorted continuous medium, there will be a possibility of the structure splitting into two branches (lineages) to ease the strain of the accumulating distortion. Energy conditions will dictate when the latter must occur.

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[14] Isotopes can not rightly be excluded from the category of an atom species which proxies for another in solid solution, although, from what is known of isotopes, the indications are that the effect of this sort of solid solution in distorting the structure would not rank as of the same order of magnitude as the effect due to solid solution of actual foreign atoms.

Unless the crystal is precipitated under equilibrium conditions, its impurity content does not have a chance to acquire a regular distribution. Under extreme circumstances, the first position occupied by an atom is its final position because it becomes immediately covered with another layer which protects it from the competition for most suitable position which must go on in crystallization under equilibrium.

Furthermore, if a gradient or directional effect of any kind is present at the time of crystallization, it may have an effect on orienting an incoming unit about to attach itself to the growing structure, or it is likely to effect a sorting action on the incoming matter so that slightly different amounts of impurities reach different places, *i.e.*, a composition gradient in the crystal is established.

As in the case of the surface crack possibility, a structure tolerant to gliding distortion may be expected to be tolerant to solid solution distortions and hence to split and give rise to lineages less frequently, *i.e.*, to grow larger lineages.

Discussion

It has just been shown that a definite "mosaic" structure is present in crystals, and it has been demonstrated that this structure does not partake of the nature of individual blocks, but rather partakes of the nature of a tree with branches arranged in a rudely spherically-symmetrical manner. Theoretical arguments have been advanced for considering this feature a result of too rapid growth to permit of the expected ideally continuous crystal. The fundamental cause of the lineages has been surmised to be either a keying-open of the Zwicky cracks or a branching of the crystal structure due to the distortions arising from misplaced solid solution impurities. Doubtless both of these effects contribute to lineage formation.

While the discussions of the possible causes of lineages have implied an application to ionic crystals, especially in the case of cracking of crystal surfaces, there is no reason why the general ideas would not apply equally to crystals bonded by other than ionic forces. In a certain sense, valence bonded crystals should prove capable of enduring a severe distortion of internal origin, for the bonding in this case is of the nature of a linking together of atoms in chains, nets, and solid meshworks. Superficially, it would appear that distortion of these chains etc. would be rather easily tolerated; the lineages would, therefore, be expected to be rather large. The large lineages of pyrite and marcasite, minerals which are quite intolerant to gliding distortions and which are not ionic, seem to favor this view.

Crystals in parallel position and dendrites can only be regarded as special cases of lineage growth. The beginnings of parallel groupings can be seen in Figures 1–4. Both these conditions evidently arise due to still more rapid growth conditions than are required to produce simple lineages, dendrites being characteristic of the most rapid growth. The essential difference between simple lineages and exaggerated cases of parallel growth is that in the former, the structure is bathed by a solution of more or less uniform concentration on all sides, so that the space between lineages is kept filled with precipitated material and the lineages are able to keep pace with the growth of one another, while in the latter case, the rapid growth allows material to be added only to the growing ends of the separated lineages, the regions of the lineage boundaries not receiving much material for growth, because it is all precipitated on the leading tips.

Interlineage boundaries appear to have an important place in theoretical mineralogy. They are often the locus of negative crystals and cavities of irregular shape,[15] which may house samples of the solution from which the mineral was deposited.[16] It also appears probable that due to the character of lineage boundaries as discontinuities in the structure of the crystal and of communicating throughout its interior, they may provide means of ingress of solutions which effect mineralogical replacement. They may also form convenient starting places for the lodging of foreign material thrown out by the process of exsolution. If this should prove to be the case, the textures of the unmixing structures and replacement structures may be based on the pattern of the lineage boundaries.[17]

[15] M. J. Buerger, The Cleavage Surfaces of Galena: To appear in a later issue of *The American Mineralogist.*

[16] M. J. Buerger, The Negative Crystal Cavities of Certain Galena, and their Brine Content: To appear in a later issue of this Journal.

[17] If both unmixing and replacement patterns are inherited from the same source, their anomalous similarity finds an explanation: W. H. Newhouse, An Examination as to the Intergrowth of Certain Minerals; *Ec. Geology*, **21**, 1926, 68–69.

That most crystals must have some sort of mosaic imperfection has long been recognized by x-ray investigators[18] who customarily allow for its effects in the calculation of the intensities of x-ray reflections. There appears to be really very little actually known about mosaic imperfections of this type, except that if allowance is made approximately for an imperfection, the intensities of x-ray reflection come out more nearly correct than if no allowance is made.[19,20] The writer submits that mosaic structure in this sense may in part be due simply to structural distortions and in part to actual lineage development, perhaps sometimes on a scale too small to be readily detected.

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[18] A very easy introduction to the situation is given by R. W. James, *X*-ray Crystallography, *London*, pages 63 and 64.

[19] See, however, the very interesting paper by Alexander Goetz, On the experimental evidence of the Mosaic Structure of Bi Single-crystals: *Proc. Nat. Acad. Sci.*, **16**, 1930, 99–105.

[20] A considerable literature on evidences in support of a mosaic structure, has appeared too late to be included in this article. The bearing of these data on the theory of lineages will be discussed in another paper.

MONTMORILLONITE OR SMECTITE AS CONSTITUENTS OF FULLER'S EARTH AND BENTONITE

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ABSTRACT

Three conclusions are supported by the investigation outlined in this paper. (1) The two hydrous aluminum silicates, montmorillonite and smectite, appear to be identical. (2) Both may be prominent as constituents of bentonite and fuller's earth. (3) Fuller's earth from one or more long recognized European localities has been formed by the alteration of volcanic ash to smectite (montmorillonite). This is a type of origin generally relied upon to determine bentonite.

GENERAL STATEMENT

Montmorillonite was described in 1847 by Damour and Salvétat.[1] Prior to that time a clay with similar physical and chemical properties had been known as smectite. This was, at that time, a common mineral name, and in the mineralogical texts of the 18th. century was used synonymously with fuller's earth. Kirwan[2] for example, in his second edition of Elements of Mineralogy (1794) used the words "walkererde" and "smectis" in addition to fuller's earth. Haüy[3] in 1801 used the terms smectite clay and fuller's earth. The general impression prevailed that smectite was a hydrous aluminum silicate containing magnesium and calcium as additional chemical constituents.[4] Early analyses[5] of smectite were somewhat questionable, although fuller's earth had been referred to in the literature since the time of Pliny,[6] A.D. 29.

The description of montmorillonite by Damour and Salvétat included a chemical study. Their analysis was more definite than the analyses of smectite then existing, although since that time better analyses of smectite have been recorded.[7] The mineral, however, appears to have escaped description by modern methods.

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[1] Damour, and Salvétat, *Ann. Chimie et de Physique*, 3rd. series, vol. **21,** 1847, p. 376.

[2] Kirwin, Richard, Elements of Mineralogy, 2nd. ed., vol. **1,** 1794, p. 184.

[3] Haüy, Abbé René Just, Traité de Mineralogie, vol. **4,** 1801, p. 444.

[4] Breithaupt, August, Handbuch der Mineralogie, vol. **2,** 1844, p. 544.

[5] Thomson, Thomas, Outlines of Mineralogy, Geology, and Mineral Analysis, vol. **1,** 1836, p. 246.

[6] The Natural History of Pliny A.D. 29. Trans. by Philemon Holland, **1601,** p. 560.

[7] Jordan, L. A., *Ann. Physik. u. Chemie, Poggendorff*, vol. **77,** Leipzig, 1849, p. 591.

Montmorillonite, on the other hand, has recently been extensively studied, and is generally recognized as one of the essential constituents of bentonite, in addition to other modes of occurrence.[8]

In connection with recent *x*-ray studies of bentonite[9] several *x*-ray diffraction patterns of smectite were taken which were noted to be identical with those of montmorillonite. Other comparative studies were then carried out on the two minerals with the conclusion that they appear to be identical.[10]

The practical significance of this conclusion is considerable. Smectite has been frequently considered to be a prominent clay mineral constituent of fuller's earth.[11] The clay mineral constituent of bentonite, however, is regarded as montmorillonite. If the two minerals are identical, the information should be of working value in studying technical applications of both bentonite and fuller's earth.[12]

The situation also raises a question of nomenclature. Which name should be retained for this clay mineral? Montmorillonite is today a well substantiated mineral name, whereas smectite, a name of prior origin is but little used at present. It would seem that the rule which calls for the least confusion in mineralogical literature would necessitate the use of the name montmorillonite, which has become common in the modern literature of clay minerals.

Examination of thin sections of smectite demonstrates that in two of the localities studied the clay has been derived by the alteration of volcanic ash. Such an origin should lead to the conclusion that, by modern definition, the clay is bentonite. We are thus placed in the apparently peculiar position of renaming a clay, bentonite, which has long been called fuller's earth. It should be pointed out, therefore, that bentonite is a rock definition while this term fuller's earth is based upon commercial application. A naturally adsorptive clay of standard efficiency would be known as a fuller's earth. This material might very well, at the same time, be derived from volcanic ash, and hence would be bentonite from the petrographic standpoint.

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[8] Ross, Clarence S. and Shannon, Earl V., *Jour. Amer. Ceram. Soc.*, vol. **9**, no. 22, 1926, p. 77.

[9] Kerr, Paul F., *Econ. Geol.*, vol. **26**, 1931, p. 153.

[10] Malthacite is probably another earlier mineral name synonymous with montmorillonite. Studies of malthacite, however, are not yet complete.

[11] English fuller's earth, for example, has long been considered to contain smectite.[11a] This has been confirmed by recent reanalysis and *x*-ray study of clay from Woburn Sands.

[11a] Woodward, H. B., Jurassic Rocks of Great Britain: *Mem. Geol. Surv.*, (London), vol. **4**, 1894.

[12] Study of the clay mineral constituents of fuller's earth is beyond the scope of this paper. Studies are under way, however, which indicate at least a partial correlation of the clay mineral constituents of fuller's earth and bentonite.

X-RAY DIFFRACTION PATTERNS OF SMECTITE AND MONTMORILLONITE

Smectite from two recognized localities has been examined recently. Several specimens from Cilly, Styria, were presented to the Egleston Mineral Collection of Columbia University by Mr. F. R. Coudert. This locality was described by Jordan. The other smectite samples were from Woburn Sands, England, and were presented by Prof. H. Ries of Cornell University. The occurrence of smectite at Woburn Sands was mentioned as long ago as 1809 by Kidd.[13]

A number of *x*-ray diffraction patterns of montmorillonite have been taken in the last few years. These include the samples described by Ross and Shannon[8] together with montmorillonite from other sources. *X*-ray work closely confirms the results of optical and chemical studies published by Ross and Shannon as previously reported.[14]

TABLE 1

X-RAY DIFFRACTION MEASUREMENTS OF SMECTITE AND MONTMORILLONITE

Line no.	Smectite or Montmorillonite	
	Outer edge in mm. from zero beam.	Spacing in A.U. × 10 cm.
1	18.3	4.49
2	20.2	4.05
3	33.0	2.48
4	49.2	1.67
5	56.1	1.47
6	64.2	1.29
7	66.2	1.250
8	74.7	1.115
9	82.0	1.020
10	85.6	0.976

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[13] Kidd, J., Outlines of Mineralogy, vol. **1**, *London*, 1809, p. 176.

[14] Bonine, C. A., Report on Sedimentation, Nat'l Research Council, No. **85**, 1928, p. 15.

An x-ray diffraction pattern of montmorillonite is shown in Fig. 1. A corresponding x-ray diffraction pattern of smectite taken at the same time in the opposite side of the same film holder appears in the lower half of the figure. The measurements agree as nearly as can be determined with those previously published for montmorillonite[15] given in table 1.

Both represent a type of pattern due to finely crystallized material. The lines are broad and somewhat diffused. In consequence, measurements are subject to variation. Patterns are not as satisfactory as those of other clay minerals.[16]

Thin sections of blue fuller's earth from Woburn Sands, contain relict structures of volcanic glass fragments in a groundmass of smectite.[17] Partially replaced fragments are also visible in places, the material of the fragments consisting of an isotropic mass with an index of refraction considerably lower than the index of refraction of smectite, presumably opal. Other less prominent isotropic remnants with an index of refraction slightly greater than smectite are probably unreplaced remnants of volcanic glass.

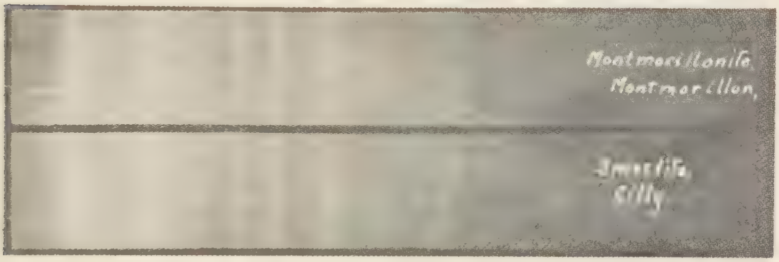

Fig. 1. Comparative x-ray diffraction patterns of montmorillonite and smectite

Thin sections of smectite from Cilly indicate that the material is more nearly pure smectite than is the case with the material at hand from Woburn Sands. Relict structures of volcanic glass are abundant, but the fragments of the glass itself or opalized glass have been entirely replaced. The alteration of volcanic ash to smectite has been almost complete.

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[15] Kerr, Paul F., *Econ. Geol*, vol. **26**, 1931, p. 153.

[16] Ross, Clarence S. and Kerr, Paul F., *U. S. Geol. Survey, Prof. Paper* No. **165E,** 1931, p. 151.

[17] Chemical studies indicate that the clay mineral constituent of the Woburn Sands fuller's earth may be beidellite, instead of montmorillonite on account of the presence of about 6 per cent of Fe_2O_3.

Such examination demonstrates that certain deposits of fuller's earth containing smectite have been formed by the alteration of volcanic ash. Ross and Shannon, however, define bentonite as follows:

> Bentonite is a *rock* composed essentially of a crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash; . . . . The characteristic clay-like mineral has a micaceous habit and facile cleavage, high birefringence, and a texture inherited from volcanic tuff or ash, and it is usually the mineral montmorillonite, but less often beidellite.

According to this definition, therefore, the clays of Cilly and Woburn Sands would now be classed as bentonite. On the other hand, from the commercial standpoint, such clays would still be classed as fuller's earth because of their natural adsorptive power.

Fuller's earth has generally been recognized as a clay with a natural high capacity for absorbing oil or grease, and also for ab-

TABLE 2

	Smectite from Cilly		Montmorillonite from France
	1	2	3
SiO_2	51.21	52.43	48.60
Al_2O_3	12.25	15.95	20.03
Fe_2O_3	2.07	1.42	1.25
FeO	—	.10	—
MgO	4.89	5.02	5.24
CaO	2.13	2.97	1.72
MnO	—	—	0.16
TiO_2	—	.08	—
SO_3	—	.22	—
P_2O_5	—	.08	—
C	—	.30	—
H_2O	27.89	13.96 (at 110°) 7.60 (over 110°)	21.52
Total	100.44	100.13	98.52

(1) Smectite, Cilly, Lower Styria, by Jordan.
(2) Smectite, Cilly, by Mr. A. M. Smoot of Ledoux & Co., N. Y.
(3) Montmorillonite, Montmorillon, France, by E. V. Shannon.

sorbing organic and mineral bases, including coloring matter, from solution in vegetable, or mineral oils. The value of fuller's earth depends upon its ability to perform one or more of these functions. The material is usually determined by a practical test of its natural adsorptive efficiency.

CHEMICAL ANALYSES

Chemical analyses show that both smectite and montmorillonite are hydrous silicates of aluminum with accompanying magnesium, calcium, and iron. The alkali elements either occur in such impurities as feldspar and mica, or are entirely absent. The moisture content is subject to considerable variation with an accompanying influence on the physical properties, notably on the indices of refraction.

Chemical analyses of smectite and montmorillonite are given in table 2.

The analyses by Smoot and by Shannon agree within the limits to be expected for such material. Both fall well within the range for the various constituents usually found in montmorillonite.

COMPARISON OF REFRACTIVE INDICES OF SMECTITE AND MONTMORILLONITE

The refractive indices of the two minerals are given in table 3. Both minerals occur in fine micaceous flakes and have moderate birefringence. The indices of refraction are in the neighborhood of 1.50 and are subject to variation with the moisture content of the mineral. If either mineral is allowed to stand in a desiccator the indices of refraction will be raised appreciably. It is probable that by careful drying two samples could be obtained that would have the same indices of refraction. On standing in the air, however, the values would decrease again, probably unevenly. In view of such considerations the figures given above show reasonable agreement.

TABLE 3

Montmorillonite from France	Smectite from Cilly
$\alpha=1.485$	$\alpha=1.490$
$\gamma=1.506$	$\gamma=1.506$
$\gamma-\alpha=.021$	$\gamma-\alpha=.016$

Values for sodium light; ± .003

ACKNOWLEDGMENTS

Dr. Clarence S. Ross and Dr. Waldemar T. Schaller of the U. S. Geological Survey have kindly gone over the manuscript of this paper and have offered a number of suggestions which have been adopted. Dr. Ross has also examined thin sections of smectite from Cilly and has emphasized the origin as bentonite. The writer wishes to express his appreciation of their interest and cooperation.

CONCLUSION

Since the x-ray diffraction patterns, chemical analyses, and refractive indices show such close relationship it seems hardly worth while to retain the two names smectite and montmorillonite for what appears to be the same mineral. In view of the large amount of modern literature on montmorillonite it seems in the best interests of science to continue the name montmorillonite, and to drop that of smectite.

Smectite has been mentioned frequently in descriptions of fuller's earth. It would naturally follow therefore that the name montmorillonite should now replace that of smectite in referring to the clay mineral constituent of fuller's earth. It should also be emphasized that bentonite is a rock while fuller's earth is a clay having a definite commercial application. It is possible for a clay which is a bentonite by origin to have adsorptive properties which make it a fuller's earth.

NOTES AND NEWS

PIPERINE AS AN IMMERSION MEDIUM IN SEDIMENTARY PETROGRAPHY

JAMES H. C. MARTENS, *West Virginia University.*

Piperine was used at least thirty years ago as an immersion medium for microscopic work, and is mentioned in several works on optical mineralogy and petrography as a suitable material for refractive index determination. Although it is probably known to most of those doing petrographic work, it has certain advantages in the examination of detrital minerals which appear to be worthy of special notice.

Directions for use of piperine together with reasons for preferring it to Canada balsam as an immersion medium for microscopic work on diatoms have been given by Chapman Jones.[1] Piperine is a definite chemical compound and is obtained in small crystals. Only the purified grade[2] is suitable for use as an immersion or mounting medium. In mounting grains in piperine it has only to be melted, not cooked, so slides may be prepared very rapidly. However, if the slides are prepared by merely heating to the melting temperature, the piperine begins to crystallize within a few days and before long this may render the slide useless. If the slides are to be kept and used repeatedly the tendency to crystallize is overcome by heating the slides in an oven at a temperature of 180°C. for one hour. This causes some darkening around the edges of the slide. If any excess of piperine extending outside the coverglass is to be removed with alcohol or other solvent this should be done before the final heating since the presence of the solvent will start crystallization. If any cloudy areas appear in slides which have been kept for a long time the slides are made clear again by heating until the piperine melts.

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[1] Jones, Chapman, Piperine as a mounting medium; *Watson's Microscope Record,* May 1925, pp. 11–12.

[2] Obtained from Eastman Kodak Company Rochester.

The refractive index of piperine (1.68) makes it especially useful for mounting heavy mineral separates from sediments. *All* of the common heavy detrital minerals have refractive indices distinctly higher than that of Canada balsam, and many of them are so much higher that it is difficult to estimate the refractive index accurately from the relief. Several of the common important heavy detrital minerals, including tourmaline, hornblende, micas, sillimanite, andalusite and collophane have refractive indices below 1.68. So does barite which occurs abundantly in the heavy portions of many well samples, and is probably authigenic in most instances.

The strong dispersion of piperine results in characteristic phenomena around the borders of mineral grains which usually make it possible to estimate the refractive index without actually observing the direction of movement of the Becke line. The colored border effects are best observed with the condenser lens out. When in focus the borders of grains with lower refractive index than the piperine appear yellow or orange. This was especially noticed on quartz, muscovite, barite, hornblende, sillimanite, and on tourmaline in the position of least absorption. If the mineral has refractive index very close to that of piperine the border appears green when the grain is in focus This was noticed on sillimanite for vibrations lengthwise of the crystal and on hypersthene.

Minerals with refractive index a moderate amount above that of piperine, say between approximate limits 1.70 and 1.76, have a blue border when the grains are in focus. Upon raising the tube slightly, a yellow line, inside of a blue one may be observed moving toward the center of the grain. This is the appearance of grains of garnet, epidote, cyanite, staurolite, augite, and chloritoid. Of course the colored borders are seen more plainly on some minerals than on others, depending upon the color of the mineral itself. Small irregular grains of light colored garnet or epidote may at first sight appear to be really blue because of the blue light due to dispersion around the borders and irregularities of the surface of the grain.

Variations in relief, corresponding to differences in refractive index, are similar to those with other immersion media. The minerals of very high refractive index, such as zircon, titanite, anatase and rutile look about the same in piperine as in Canada balsam. They are easily distinguished from minerals having a refractive index between 1.70 and 1.80 by the stronger relief and by the borders appearing dark rather than colored. Xenotime has both its refractive indices ($\epsilon = 1.816$, $\omega = 1.721$) above that of piperine, but when mounted in that substance it is easily distinguished from zircon, which has similar crystallization and like optical sign, by showing low relief and exhibiting colored borders for light vibrating parallel to the base. With a quarter turn of the stage the xenotime crystal shows much stronger relief, while the relief of the zircon is high and not appreciably different in the two positions. Using piperine as an immersion medium xenotime was found in the heavy separates from several sediments in which it had been overlooked when using Canada balsam to mount the heavy minerals.

BOOK REVIEW

THE MINERALS OF CONNECTICUT. JOHN FRANK SCHAIRER. Bulletin **51**, *Connecticut State Geological and Natural History Survey*. VII+121 pages, 14 figures.

This non-technical bulletin has been prepared mainly for teachers and the general reader interested in the minerals of Connecticut. The discussion is taken up under three main divisions. In part 1, the physical and chemical properties of minerals are discussed, followed by a description, alphabetically arranged, of more than one hundred minerals found in Connecticut. Part II considers briefly the origin and occurrence of rocks and minerals, also the subsequent changes brought about by weathering, contact and dynamic metamorphism, secondary enrichment, etc. The last portion (Part III) lists special mineral localities with a brief statement of the minerals found in each. A bibliography is likewise included.

The bulletin is a pamphlet of 121 pages and may be obtained from the State Librarian, Mr. George S. Godard, Hartford, Conn. Price 75¢, plus 6¢ for postage, although public libraries, colleges, scientific institutions and teachers who require the bulletin for their work may secure it without charge.

W.F.H.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, February 4, 1932

A stated meeting of the Philadelphia Mineralogical Society was held on the above date with Dr. Cajori presiding. Twenty-six members and fourteen visitors were present.

Dr. Alfred C. Hawkins of Rutgers College addressed the Society on "The Microscopic Minerals of the Clays of Middlesex County, New Jersey." Minerals found in these clays include pyrite, zircon, garnet, quartz, pyroxene, rutile, albite, tourmaline, hematite, enstatite, azurite, biotite, magnetite, ilmenite, muscovite, hypersthene, and laumontite. The clays were deposited on rough and irregular surfaces and filled depressions; they were then covered by sands. Many artesian wells have been drilled in the area, and the clays have been worked for kaolin and fireclay, in open cuts. Microscopic crystals of tourmaline, doubly terminated, which were present in the clays were traced by Dr. Hawkins to a schist near Putney, Vermont. The talk was illustrated by charts and lantern slides. A rising vote of thanks was tendered to the speaker.

Local trips were reported by Messrs. Knabe and Oldach. Dr. Hawkins reported on a trip to Canaan, Conn., and Grafton, New Hampshire.

WILEY H. FLACK, *Secretary*

MINERALOGICAL SOCIETY OF SOUTHERN CALIFORNIA

The ninth meeting of the Mineralogical Society of Southern California was held in the Lecture Hall of the Pasadena Public Library on Monday, March 14, 1932. Mr. Joseph Barbeiri gave a demonstration lecture on "Chipping and Flaking of Flint Artifacts." On March 20 a field trip was taken to the Pala gem mines, San Diego County.

E. VAN AMRINGE, *Secretary*